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Soil and Soil Maps

D. MACKNEY

Soil Survey of England and Wales

THE PURPOSE of this article is to give a brief background to the science of pedology and the applied science of soil survey and to point to some of the important interpretative work which needs to be done on the soil units of soil maps by survey staff, research workers, and advisory officers.

Pedology is the science which deals with the classification and genesis of soils. It developed from other sciences, such as geology and chemistry, when Russian workers realized that the characteristics of soils depended upon their geographical position. This can be simply illustrated:

> Rocks are natural bodies which do not vary with their environment. A granite in the Antarctic may be identical with a granite at the Equator, and in these circumstances it would have a similar chemical composition, but the soils which develop on these granites will be quite different. Though the chemistry of the soil parent material is the same, other factors, for example, rainfall, temperature and vegetation, modify the rock through weathering and evolution to produce quite different soils.

The science is based then on the conception of soils as natural, independent bodies, which they are if their variation is conditioned by geographical factors such as climate. This means that soils can be recognized as natural units occurring on the earth's surface in the same natural way as do forests, animals, and man. Pedology is a science in its own right, not a facet of geology, because it deals with the animate and inanimate matter of which the soil is comprised, such as animals, plants, bacteria, water, air, as well as minerals derived from geological formations. When one looks at a soil profile it is not just a haphazard collection of mineral, rock and roots, but a faithful mirror of its environment, a reflection of its genesis. It is the job of the pedologist to understand the factors which constitute the environment and read the clues to soil profile development which are present. Quite obviously this sort of approach to the origin of soils is best made through an examination of sites which have not been drastically altered by man.

In countries like Britain, however, where utilization of land has been extensive, few natural or even semi-natural sites remain. Thus, to the difficulty of interpretation is added another factor which some regard as the most significant of all: the influence of man. Tillage and deforestation have both altered the succession of horizons which form the soil profile—the unit of study in pedology.

However, although the task is made more difficult, it is also the job of the pedologist to estimate the effect of man's activities on soil profile

characteristics. In detail, the pedologist is concerned with processes in soils, attempting to answer questions like these:

> Is clay being mobilized in upper horizons and washed down to lower ones?
> Do particular soil horizons represent development in a climate like today's, or are they remnant horizons giving a clue to past climates?

Furthermore, stimulated by inquiries from agriculture, he is concerned in studies of soil drainage, structure and many other related problems.

The mapping of soils, or soil survey has developed out of the scientific concepts of pedology. Soil survey is, therefore, the applied science which attempts to show the variation of soils in map form. There is often no clear line of separation between the pedologist and the soil surveyor and in Britain the titles are synonymous.

Soil Survey

Soil is a three-dimensional layer which lies over the surface of the earth on rock or its weathered products. A vertical section cut through the soil exposes a succession of layers, known as horizons, and these together constitute the soil profile. The horizons are called A, B and C by convention, though there may be several sub-divisions of each. An examination of the layers which form a podzol will explain the idea of soil horizons and soil profiles. A podzol is a soil which occurs in parts of this country on acid, light-textured parent materials. The essential process in its formation consists of leaching, i.e., washing down, of humus and iron from upper horizons and deposition in lower ones.

"A" HORIZON

The A horizon is the upper layer of the soil profile in which soil life in plant and animal form is most abundant. Through the percolation of rainwater, soluble mineral and organic substances are removed to lower horizons or are lost in drainage water—the process of leaching. It may be sub-divided into a layer where plant debris has accumulated to form a zone very high in organic matter, and below this and sharply separated from it, a zone from which iron has been leached, producing a mineral skeleton, grey or white in colour.

"B" HORIZON

The B horizon lies immediately below the A horizon and is a layer in which leached material is in part deposited. This may also be subdivided into a layer rich in colloidal organic matter, below which is a rusty-brown zone rich in iron.

"C" HORIZON

The C horizon is the parent material of the soil. It may be regarded as the reference layer, for comparison with this demonstrates the degree and form of soil horizon differentiation.

It is the job of the soil surveyor to recognize the characteristics, for example, colour, texture, structure, and porosity of soil profiles exposed by either auger or spade, and to group them into significant units to form a soil map. The soil profile is thus the basis of mapping. The range of variation of soil characteristics within a separated unit on the map is largely controlled by the purpose for which the map is intended. The detail required for a survey of an experimental site is not essential for a reconnaissance map, which may be intended for educational purposes, and thus the units on these maps are different.

In field-by-field surveys using 6 in.–1 mile maps, the normal survey unit is the soil series, and larger units than this are generally described in terms of several soil series. A soil series consists of a number of soil profiles, which though not identical, are sufficiently homogeneous to form a significant unit. It is described on a single parent material and has an agreed limited range of variation of soil profile characteristics. Generally a locality name is given, for example, the Bromyard Series, which links it geographically to an area where the soils are well expressed.

Boundary Drawing

Bearing in mind the units to be mapped, boundaries are drawn which link them to the landscape. Boundary drawing is interpretative work and is as much an art as a science, for the surveyor has to utilize the little information he obtains from auger borings at points in the landscape to indicate soil variation over the whole landscape. Since he cannot see the soil profile except where he has exposed it, it is necessary to use the clues to soil profile morphology which are offered by systems he can see. For example, the influence of relief on soil formation enables the surveyor—once he understands this influence—to interpret soil profile development in terms of land form. In consequence, it is not surprising that soil boundaries often conform to topographical ones. In a similar way the type of vegetation, particularly in semi-natural areas, often indicates a specific soil environment which helps the surveyor to estimate the true position of the soil boundary.

Morphological Clues

The study of soils in the field is based on morphology, for it is not possible to make chemical analysis at each point investigated, even if this were advisable. The surveyor relies on his tested ability to estimate some chemical features in the profile from morphology—soil colour gives many clues. Iron compounds largely control the colour of soils. When soils are red or brown, iron is normally in the oxidized or ferric state and relatively immobile; when soils are grey or blue-grey, iron is in the reduced or ferrous state and mobile. These colour differences are also clues to the soil environment, for grey horizons frequently imply waterlogging or impedance. In waterlogged conditions air is excluded by the presence of water in pores and fissures, reducing conditions

operate, ferric iron becomes ferrous iron, and the soil changes from red or brown to grey (the colour of ferrous compounds).

Another morphological clue to the chemistry of soils is the occurrence of white or pinkish flecks in profiles and these indicate the presence of calcium carbonate. Round, small, black concretions, and coatings on structure faces, often contain very much higher quantities of manganese than the soil surrounding them, and this can be confirmed in the field by use of hydrogen peroxide.

There are many other morphological features which the surveyor examines and records. These include soil texture, soil structure, estimate of organic matter content, moisture, stoniness, fauna (in cultivated and grassland soils mainly the activities of earthworms), the size, shape and distribution of roots, the nature of the parent material, as well as notes on vegetation, system of farming, slope and aspect.

Though mapping is in general based on morphology, the properties of soils cannot all be estimated in the field. Laboratory determinations are essential for a true understanding of pedological processes and they often provide evidence where the interpretation of soil morphology is problematic. In soil survey investigations, therefore, field work in partnership with laboratory work results in the separation of significant units, many of the physical and chemical properties of which are known.

Significance of Soil Maps

Although the scientific information which soil surveys produce is utilized by a large number of organizations, there is a unique link with agriculture. Almost all the field investigations in this country into the origins and variability of soils have been stimulated by agricultural colleges and experimental stations directly connected with agricultural research. Naturally, farmers and their advisers are interested in soil, and in a large measure the work which soil surveyors do is intended to be useful to agriculture.

The common soil terminology which exists between N.A.A.S. officers and surveyors allows discussion of the influence of soil on agriculture, and through the variety of problems which arise in advisory work, many contacts have been made which are mutually beneficial. Already, advisers and surveyors co-operate in the selection of experimental sites and in general advisory visits, but despite this tie-up between soil survey work and practical agriculture, the link is not as effective as it might be.

The main reason for this is that as yet relatively few soil surveys are available in published form. Gradually this position will change as more maps are prepared. However, so that these maps contribute their true weight to the science of agriculture, it is necessary to understand the level at which soil surveys contribute information. Criticism of the utility of soil surveys has largely stemmed from some misconceptions of what soil maps mean.

Soil maps provide a great deal of basic information, but they are rarely intended to solve agricultural, or any other problems by their existence alone. The position of soil surveys in relation to agriculture is analogous to the relationship of geological surveys to the coal industry: the geologist maps the coal seams and faults, but it is the engineer's job to organize the extraction of coal.

One of the best examples of the usefulness of soil surveys to advisers in this country was the survey of the fruit area in the Vale of Evesham.* This was not only a soil survey but also an examination of the productivity of soil series in terms of fruit production.

Productivity Assessments Needed

One of the great planning needs, therefore, is an investigation of the significance to agriculture of the units separated on soil maps, so that the practical importance and productivity of these units can be established.

The "productivity" of soils depends upon the aggregate effect on crop production of environmental factors such as soil, climate, temperature, aspect and altitude, as well as management. Setting aside economic considerations (e.g., proximity to markets), productivity is a complex concept which in its simplest terms merely reflects the average yields of various crops. It is clear that different soils have variable production capacities for the same crop, and these variations stem from differences in soil properties as well as from management.

The differentiated units which comprise soil maps allow investigation into the productivity of these units, since many of the other influencing factors are known. Furthermore, the information resulting from these investigations can be widely applied, even to unmapped areas where similar soils exist. The kind of data required to produce productivity ratings for soil and yield prediction figures is not readily available. However, there is much accurate information from work done in experimental stations, experimental farms, and farm institutes, and this could be incorporated with exact yield figures obtained from farms for sugar beet, potatoes and grain.

Soil Survey should be followed by Yield Predictions and Productivity Ratings

In America special sections of the soil survey follow up the mapping teams and record the yield details for soil units mapped; they combine these data with those obtained from experimental farms, and issue yield prediction figures and productivity ratings.

This kind of investigational work into the productivity of soil units should be an important phase which follows soil survey. Obviously, the large number of soil units already separated precludes an investigation of each. However, the selection for experimentation of a restricted number of important soil series of known genetic relationships provides

* A Survey of the Soils and Fruit in the Vale of Evesham 1926–34. Bulletin No. 116 of the Ministry of Agriculture, Fisheries & Food, December 1949.

the basis for extending findings to larger numbers of related soils. For this work to be of the maximum use, considerable care will be necessary in choosing sites which are representative, not only of the soil series chosen for experimentation, but also of the climate in which these soils are found.

Quite a store of information already exists which may help to build up the basic data required to estimate productivity. In mapped areas it is possible to characterize soils in terms of chemical data for phosphate, potash, organic matter and lime requirement, by extracting this information from soil analysis cards. Each soil series would have a range of values, depending on the type of management, and the standard of farming. However, at similar farming levels genetically related soil series should have similar ranges of values, but there should be considerable differences in genetically different soils.

Soil survey interpretation may take a variety of forms depending upon the purposes for which it is required. A wide range of maps can be constructed from the basic soil survey, for example, soil-suitability maps (the suitability of soils for particular crop production), maps which show water relationships and availability of water for crop growth, building-site-suitability maps, soil-texture maps, and many others.

Many of these maps cannot be constructed from the basic information provided in the soil map and report alone, but where there has been integration of the results of experimental work with this information, soil survey interpretation is possible.

Conclusion

The importance of the soil survey to agriculture and other organizations interested in soil is that it is based upon soil profiles, which are products of the operation of a natural system. Since it is impossible to deal with a large number of soil profiles, it is necessary to group them into significant mapping units, the individual profiles of which have general characteristics determined by the same natural system. Soils are neither the same everywhere nor are they a large series of unconnected indeterminate bodies of matter. The whole science of pedology is based on the conception of a natural system working continuously to produce soil profile variation. Given the necessary knowledge of climate, vegetation and other factors, it should be possible for a pedologist to predict the morphology of a soil profile he has never seen—this is the ultimate expression of system.

It is possible that considerable advances in the understanding of problems in agriculture can be made by investigating them in the light of the natural system which determines soil profile variation. This does not mean that soil maps are likely to solve the problems of plant pathology, entomology or crop husbandry, but they should perhaps allow a better understanding of the soil environment in which these problems are active.

New Breeding Methods for Brussels Sprouts

A. G. JOHNSON

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PRESENT-DAY VARIETIES of many Brassica crops are notoriously variable from plant to plant. Trial results indicate that in one of the better stocks of 'January King' cabbage, only about two-thirds of the plants produce top-grade marketable heads, the rest being off-type. Similarly, less than two-thirds of the potential Brussels sprouts crop is in marketable form, partly because weak or off-type plants make little contribution to the crop, or the sprouts are of unmarketable quality. One aspect of the work at this station is to try new methods of breeding Brassica crops with the object of improving uniformity in quality and yield. At present most of the work is with Brussels sprouts, but it is expected that any method successful with this crop will also be useful with other botanical varieties of *Brassica oleracea*.

The Problem

Brussels sprouts, in common with most of the other cultivated varieties of *Brassica oleracea*, are predominantly cross-pollinated and virtually self-sterile, though a few self-fertile plants are found. Cross-pollination leads to heterozygosity of almost all the plants. Selections are made on the phenotype, but the phenotype of a plant may not reveal the genotype. In a heterozygous plant, the recessive genes produce little or no visible effect on the phenotype, because their effects are masked by those of their dominant alleles. Thus, the phenotype provides information only on the dominant genes, and gives little indication about the number or nature of the recessive genes present. Consequently, although undesirable dominant genes are readily eliminated by selection, because they exert a visible effect on the phenotype even in the heterozygous condition, many undesirable recessive genes are preserved in spite of selection. When heterozygous plants are seeded, however, segregation results in the production of offspring in which recessive genes are present in the homozygous condition; hence they exert a visible effect. The characters determined by the recessive genes therefore reappear in the offspring. It follows that almost all the undesirable characters remaining in highly-bred varieties are governed by recessive genes.

Progeny Testing

By chance, some of the plants selected for seed production carry fewer recessive genes for undesirable characters than others. Even after mass pollination, in which all plants have contributed pollen, genetically

superior plants produce better and more uniform progeny than do genetically inferior plants. The better progenies are also, on average, genetically superior and so provide improved material for further breeding. A simple progeny test is now being suggested [1] in which the seed produced by each plant is kept separately and a sample of plants is grown from each separate packet of seeds so obtained. On the basis of the performance of these samples the remainder of the seed derived from each of the original parent plants is either rejected or retained. Only that seed which has been retained is bulked to produce the next crop. Stocks produced by this method have given up to 30 per cent increase in marketable yield, compared with the original stocks from which they were developed.

Although this method is useful, it is by no means the complete answer to the production of better varieties. Each progeny consists of plants which may have resulted from pollination by any of the other plants present in the seeding plot. Rejection of the seeds produced by the inferior parents reduces their influence on the next generation. Their influence is not entirely removed, however, since all the plants have been pollinators and hence all the genotypes present in the seeding plot are represented in each progeny.

Inbreeding

Some form of inbreeding is necessary for further improvement; the best and most direct method being self-pollination, that is, application to the stigma of pollen from the same flower, or from another flower of the same plant. Self-pollination results in segregation of numerous homozygotes, and simplifies the interpretation of results. The homozygosity so obtained can be maintained by continued self-pollination.

Owing to the self-incompatibility of most Brussels sprouts plants, self-pollination at the bud stage [2] is practised as a standard procedure at this station to ensure a good set of selfed seed. Bud pollination also ensures that there is no selection of self-compatible lines, which could be a disadvantage in later stages of the work. Tests have shown that self-pollination in the bud stage for three successive generations gave no increase in self-compatibility in any of the lines tested, when compared with the non-inbred parent plants from which they were derived. It is probable that the substance which restricts pollen growth does not appear in the stigma until shortly before the flower opens [2]. Thus, bud pollination allows the growth of all pollen. In contrast, when an open flower of a self-incompatible plant is self-pollinated, only a limited proportion of the pollen grows. Possibly the pollen that grows carries mutant compatibility factors which have enabled it to do so.

About 50 buds are normally pollinated with pollen from open flowers of the same plant, when a selfed progeny is required. On average, this produces sufficient seed to grow 100 or more plants in the field, though the amount of seed varies considerably from plant to plant.

WORK ON THREE CAMBRIDGE VARIETIES

Most of the inbreeding work so far has been on lines derived from selected plants of the three Brussels sprouts varieties 'Cambridge No. 1', 'Cambridge No. 3', and 'Cambridge Special'. In each of these varieties, very obvious differences in type were found between first selfed-generation (S.1) lines, even when the non-inbred parent plants had been selected for their similarity in appearance to one another. The parent plants were initially selected for the production of breeder's stock seed of the variety in question, and were thus as true to the ideal type as could be obtained in this manner. Nevertheless, about two-thirds of the S.1 lines from these plants contained a high proportion of plants with such major defects as early bolting, tight "cabbage" heads, plants falling over, many sprouts missing, sprouts susceptible to rotting or with various malformations. These latter were the most numerous. This concentration of deleterious characters was not peculiar to the Cambridge varieties. Other varieties, though as yet inbred on a smaller scale, have produced an even larger proportion of S.1 lines showing major defects. In each variety, plants for further selfing were selected from those lines showing the least number of plants with major defects. The remaining two-thirds of the lines were rejected because of their defects.

Each S.1 line was more uniform than the parent variety, in that only a particular part of the total variability of the variety was exhibited by any one line. However, considerable variability still remained within each S.1 line as a result of segregation of different genotypes. Because of this segregation it was often possible to produce S.2 lines free from a particular defect, from selected good plants of an S.1, although some plants of that S.1 line showed the defect. In other cases S.2 lines, or related groups of S.2 lines, were rejected because of the increase of uniformity for major defects. As the process was continued in successive generations, the lines retained became steadily more uniform for desirable characteristics.

Some of the material has now reached the S.4 stage and is virtually homozygous for genes of economic importance and practically free from undesirable characters. Inbreeding is being continued to discover if it has any further effects, but for practical purposes three or four generations of selfing seem to be sufficient. It is probable that the inbred lines can then be maintained by mass pollination between sister plants of each line, in strict isolation. This method of maintenance is being tested and has so far given satisfactory results.

INBREEDING DEPRESSION

Inbreeding depression has occurred in the material, but not to such a degree as might have been expected. This may be partly the result of

rejection of those lines showing the greatest depression, irrespective of their type. Also, some lines were lost through failure to set seed, which may have been the manifestation of the most extreme inbreeding depression. Thus, the sample retained in the breeding programme may not have been a random one. On average, plants of the S.3 lines retained in the breeding programme were about 75–80 per cent of the general size and vigour of plants of the comparable non-inbred variety. There were, however, some lines which showed little or no inbreeding depression. These might have been lines in which selection had resulted in retention of heterozygosity, but this is unlikely as there was no appreciable difference in uniformity between the vigorous and less vigorous inbred lines.

In each of the varieties used in this investigation, only about 3 or 4 of about 30 out-bred plants originally selected gave useful S.3 or S.4 inbred lines. Furthermore, the range of characteristics involved in producing a "good" Brussels sprout plant is so wide that it would be extremely difficult to find an inbred line which was perfect in all respects. Fortunately both this and the inbreeding depression can be overcome by crossing inbred lines to produce hybrids.

Hybridization

Crossing two unrelated inbred lines to produce a hybrid variety restores heterozygosity, and as a result vigour is also restored. Sometimes the vigour of the hybrid plants is even greater than that of the original out-bred plants. Since each inbred line is virtually homozygous for factors of economic importance, it must contribute an identical genotype to each hybrid plant. Thus, the hybrid variety is as uniform as the inbred lines which produced it. A further advantage of the hybrid variety is that the different characteristics of two inbred lines can often be combined. An inbred line conferring good cropping ability but only moderate sprout quality may be combined with a second inbred line conferring good quality but rather poor cropping ability, to produce a hybrid variety giving a heavy crop of high-quality sprouts.

At present the different inbred lines must be test-crossed one with another in all possible combinations to determine their ability to combine to produce a hybrid with as many of the desirable qualities as possible. Since this involves a large number of crosses, simpler testing methods are being investigated, but no results are yet available. In 1957 and 1958 field trials, forty-three test hybrids were grown, each produced by crossing a pair of unrelated inbred lines. For each hybrid, one of the pair of inbred lines was derived from either 'Cambridge No. 1' or 'Cambridge No. 3', and the other was an inbred line from 'Cambridge Special'. Because of its high sprout quality, an inbred line from 'Cambridge Special' was always used as one of the lines in the cross. All but three of these forty-three hybrids gave a greater marketable yield than the higher-yielding out-bred parent variety. Further, six of

these hybrids exceeded the yield of their respective higher-yielding parent variety by 50 per cent or more, and the best hybrid gave a marketable yield which was 66 per cent better than that of its higher-yielding parent variety.

Measurement of the hybrid plants showed that they were about 25 per cent larger and more vigorous than the plants of the larger parent variety, although no increase could be detected in the size of the individual sprout buttons. Thus, increase in plant size accounted for part only of the increase obtained in marketable yield; the remainder was probably the result of greater uniformity. This affected the yield in two ways, firstly by giving a larger number of sprouts on a greater proportion of plants, and secondly by improving the average quality of individual sprouts to give a greater proportion in the marketable grade.

Hybrid Seed Production

The small quantities of hybrid seed needed for test purposes are produced by hand pollination in isolation bags. Commercially it would be necessary to produce hybrid seed in much larger quantities at a more reasonable cost, and this would require a different technique. It is not normally feasible to produce hybrid seed by planting alternate rows of two inbreds and allowing natural pollination to take place. Under these conditions approximately half the seed on each plant is the result of "sib" crossing, that is brother–sister crosses between plants of the same line, instead of from crossing between plants of two different lines. It has been suggested [3] that inbred lines could be bred in such a way that plants of the same line would be incompatible with each other, but compatible with all plants of an unrelated line. Attempts to do this with Brussels sprout material have not yet been successful. There are, however, several other methods which are being tested, but no definite results are yet available and the following is intended only as a general indication of the possibilities.

The most promising method utilizes male-sterile plants in which the anthers shrivel and fail to produce pollen. Such plants have been found in a number of the Brussels sprout breeding lines [4]. If all the plants of one of the inbred lines to be crossed are male-sterile, sib crossing within this line is impossible, and all the seed produced by the male-sterile plants must be hybrid. The seed produced by the plants of the other, male-fertile line is the result of sib crossing between plants of that line. This seed can be used to produce the next generation of the line, thus removing the need for a separate seeding for maintenance purposes.

The male sterility which has been found in the Brussels sprout material is inherited as a simple recessive, the male-sterile plants being the double (homozygous) recessives. Since two male-sterile plants cannot be crossed, a pure line of male-steriles cannot be obtained. The male-sterile material must be maintained, therefore, by crossing homozygous male-sterile plants with male-fertile plants which are hetero-

zygous for the male-sterility gene. This will produce a population in which half the plants are homozygous male-sterile and half are heterozygous. These latter male-fertile plants would have to be removed at flowering time from a crop destined to produce hybrid seed. It may be possible to improve on this method, for instance, by finding a cytoplasmic modifier such as that found in onions [5], which under certain circumstances can cause a plant homozygous for male sterility to produce pollen. Alternatively, it may be possible to find a seedling marker linked to male sterility so that homozygotes could be identified in the seedling stage, and the heterozygotes could then be discarded before planting.

"SINGLE- AND DOUBLE-CROSS" HYBRIDS

The hybrids so far tested have been the direct result of crossing two inbred lines, and are known as "single-cross" hybrids. Since the inbred plants may be relatively weak, the quantity of single-cross hybrid seed obtained per inbred plant crossed may be too low to enable the production of commercial hybrid seed at an economic price. It is, however, possible to produce "double-cross" hybrid seed by crossing two unrelated single-cross hybrids. Thus, the relatively expensive single-cross seed becomes a stage in the multiplication process, instead of being the final commercial product. It remains to be investigated whether male sterility can be used in the production of both the single- and double-cross seed, and whether the double-cross hybrid varieties will prove as successful in crop production as the single-cross hybrids.

SYNTHETIC VARIETIES

Another possible use of inbred lines is in the re-synthesis of an existing variety by mass crossing between an unspecified number of inbred lines derived from that variety. Such a "synthetic" may not be as uniform as the single- or double-cross hybrids because of segregation of the various characteristics derived from the large number of different inbred lines. However, inbreeding will have eliminated the greater part of the undesirable characters affecting crop quality and yield, and it is likely that the synthetic would produce a greater yield than the original variety. The production of synthetics is being investigated, but results are not yet available.

Summary

Investigations at the National Vegetable Research Station have shown that considerable improvement can be obtained in Brussels sprouts by applying new breeding methods. In particular, inbreeding followed by hybridization has given as much as 66 per cent increase in the marketable crop as compared with the out-bred variety from which the breeding material was derived. This work is still in progress, but several problems must be overcome before hybrid seed can be produced on a

commercial basis. Special emphasis is now being given to work on these problems since it is felt that the effort is justified by the promising results obtained so far.

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Development of Insect Resistance to Insecticides

M. J. WAY

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IN little more than ten years about forty species of insects of public health importance have developed resistance to the synthetic organic insecticides which formerly controlled them. This severe setback to the large-scale campaigns against insect- and tick-borne diseases has led to much work on resistance particularly in houseflies and mosquitoes. The problem, however, is not recent, nor is it confined to insects of medical importance, for it first arose in pest control on fruit crops. In 1908 lime-sulphur failed to control the San José scale in parts of the U.S.A. even when applied at a dose ten times greater than that which formerly gave excellent control [1]. During the next twenty years, other fruit insects, notably four species of scale insect [2 and 3] and the codling moth [4], developed resistance to hydrogen cyanide fumigation and to arsenicals respectively.

By 1943 the resistance of codling moth in Virginia, U.S.A. could not be overcome by trebling the number of spray applications, by doubling the volume of spray applied each time, by increasing the dose of arsenic or by various other refinements [5]. Arsenic-resistant ticks appeared in South Africa [6] and citrus thrips resistant to tartar emetic in California [7]. Cyanide-resistant strains of *Drosophila*, cotton aphids and flour beetles were produced by artificial selection in the laboratory [8 and 9]. Thus, there was good evidence that the enormous increase in chemical control measures which followed the recent discovery of synthetic organic insecticides would soon produce many more examples of insect resistance.

Insects of Public Health Importance

Resistance to synthetic insecticides has developed in species of bedbugs, ticks and cockroaches as well as in many species of flies. In increasingly large areas throughout the world, houseflies and mosquitoes have developed resistance to chlorinated hydrocarbon insecticides such as DDT, γBHC, and dieldrin [10]. Sometimes they have become practically immune. Thus, certain strains of mosquitoes have a resistance of about 300 times normal to DDT and 800 times normal to dieldrin. As a result, one authority has concluded that chlorinated hydrocarbons have no future for fly control [11], which is particularly depressing because DDT, for example, is almost the ideal insecticide, as it is cheap, highly active and persistent, and comparatively safe to use.

Failures in housefly control by chlorinated hydrocarbon insecticides have led to the use of organo-phosphorus insecticides, and although the levels of resistance which have arisen are low compared with those

shown towards chlorinated hydrocarbon insecticides they are beginning to prevent effective control [12].

Insects of Agricultural Importance

Insecticides, mostly synthetic organic chemicals, are now widely used in agriculture though only in comparatively small areas are they applied as intensively as in the campaigns against insects of medical importance. The early instances of development of resistance have been mentioned. Recent records include DDT resistance in the codling moth [13 and 14], small cabbage white butterfly [15], potato flea beetles [16 and 17], Colorado potato beetle [18] and diamond-back moth [19], DDD resistance in the red-banded leaf roller [20], aldrin, dieldrin and heptachlor resistance in the onion fly [21] and parathion resistance in the walnut, green peach and spotted alfalfa aphids [22, 23, and 24].

These species have developed resistance in comparatively small areas mostly in North America, not in Europe, and their increased resistance, although often enough to make control ineffective, is less than in some species important for public health. Thus, there are records of respectively about 7 and 4 times normal resistance to parathion in the walnut and spotted alfalfa aphids, about 8 times normal resistance to DDD in the red-banded leaf roller, and 8 times normal to DDT in the Colorado potato beetle. A more generally serious problem is that of glasshouse and fruit tree spider mite species which have developed resistance to organophosphates and to other acaricides in Europe, including Great Britain, as well as in North America [25, 26, 27, 28, 29, 30, 31, and 32].

Moreover, an enormous increase in resistance seems possible. For example, in a Californian lemon grove treated with parathion and demeton, the citrus red mite became resistant to demeton and to other systemic phosphorus insecticides such as trithion. Laboratory experiments indicated that the resistant mites had become over 200 times and over 15,000 times more resistant than normal mites to residual films of demeton and trithion respectively [29]. Strains of the glasshouse red spider have developed in Great Britain which are about 10 times more resistant than normal to parathion and which also resist other acaricides. This has necessitated the return to petroleum oil emulsions for controlling spider mites on cucumbers [32].

Nature of Resistance

There is no evidence that an insect can acquire tolerance to an insecticide during its lifetime, that present-day insecticides induce mutations for resistance or that they affect the normal mutation rate in an insect. Resistant strains apparently arise solely by selection of the more resistant individuals, which then form the nucleus of subsequent populations. In this way populations have become resistant quite quickly—after five or six generations of the potato flea beetle [16 and 17] and after about fifteen generations of the small cabbage white butterfly [15]. Resistant individuals may be present in the population

before any insecticide is applied or they may arise later by chance mutations. Thus, the rate of appearance of resistant mutants may influence the rate at which resistance develops, and, if such mutations do not occur, the population will not become resistant despite years of insecticide pressure [33].

It seems that resistance has developed quickly during campaigns against insects of public health importance partly because the vast scale of some operations ensured that the rare resistant individuals were found [11]. Nevertheless, the independent development of resistance in small isolated populations of the same species of scale insect, red spider mite and housefly, shows that resistant individuals are likely to occur quite frequently in some species. For example, the resistance of the two-spotted spider mite to hexaethyl tetraphosphate apparently developed independently in at least thirty-three different glasshouses [26].

Ability to resist the action of the insecticide is, of course, inherited, as demonstrated by early classical work [34 and 9]. Single genes confer cyanide and dieldrin resistance respectively to the California red scale [34] and a species of mosquito [35]. DDT-resistance in the housefly can come either from a single gene or from a combination of genes [36]. It may be that resistance sometimes arises from the chance throwing of rare genetic combinations [37]. Once they have appeared, their frequency in the population rises, like that of single resistance-conferring genes, at a rate which generally depends on the intensity of selection by the insecticide. The development of resistance must therefore be regarded as a dynamic process with resistance likely to become more and more common as chemical control measures are intensified.

Specific Resistance to Different Insecticides

Three different types of inherited resistance have been recognized. First, a relatively small increase in resistance to all poisons, called "vigour tolerance" [38], which, as the name implies, indicates an especially vigorous strain. Second, there are instances of "behaviouristic resistance" [39 and 10], such as hypersensitivity to insecticide films and poison baits. Both types of resistance are unimportant compared with the specific resistance to a particular group of poisons, which is the type that can make the insect practically immune.

In the following groups, development of resistance to one chemical generally confers resistance to others of the same group but usually does not confer "cross-resistance" to chemicals of other groups:

> I: DDT and its analogues; II: γBHC, aldrin, dieldrin, heptachlor and related compounds; III: organo-phosphorus insecticides; IV: nitroparaffins; V: thiocyanates; VI: carbamates; VII: pyrethrins.

This important aspect of present work on resistance is reviewed in some detail by Brown [10].

It is a complex problem; for example, the development of DDT resistance does not also confer resistance to phosphorus insecticides, whereas development of resistance to phosphorus insecticides usually confers high resistance to the DDT and γBHC groups [40]. Further, within the group of phosphorus insecticides there is evidence that spider mites which develop resistance to parathion may remain susceptible to TEPP [26] or malathion [41]. It is particularly important if the development of resistance to one chemical makes the insect more susceptible than normal to another [42]. However, after exposure to insecticides of two different groups, either simultaneously or successively, insect populations may become resistant to both.

Loss of Resistance when the Insecticide Treatment is Discontinued

Cyanide-resistant strains of the Californian red scale remained resistant even when reared in the laboratory without exposure to cyanide during sixty-five to seventy generations, the equivalent of twenty-five to thirty years in nature [43], whereas in field and laboratory some resistant housefly populations lost, and others retained, DDT resistance when the insecticide treatment was discontinued. Unfortunately, resistance, if lost, is likely to return very quickly when the insecticide treatment is restarted [10]. Thus, an insecticide may become permanently useless or unsatisfactory for controlling insects which have developed resistance to it.

Factors Favouring Development of Resistance

It is important to know the conditions that favour development of resistance so that they can be avoided as far as possible. As mentioned already, resistant individuals must be present in the population and whether they are found and selected depends on the amount and scale of the insecticide treatment. The development of resistance is favoured by continual use of the same type of insecticide and will also depend on:

1. *The nature of the insecticide and the method of application.* Insecticides which form persistent residues on surfaces or in the soil favour the selection of resistant strains, so where practicable, non-persistent insecticides should be used, and seed dressings, for example, are preferable to soil treatments because their rates of application are probably too low to leave significant soil residues.
2. *How frequently an insecticide is applied.* Routine spray programmes regardless of pest incidence as practised in many fruit orchards are potentially dangerous because they maintain the "insecticide pressure" which is necessary for developing resistant strains and also because they prevent natural controlling factors, such as parasites and predators, from offsetting the selection of resistant individuals by the insecticide.

3. *The pest species.* Species with many generations each year, such as spider mites, aphids and houseflies, are likely to develop resistance more quickly than those with few. Those with limited powers of dispersal, such as scale insects and spider mites, which form permanent isolated populations in orchards and in glasshouses are especially liable to develop resistant strains. Resistance is also likely in species which do not normally breed on weeds and are confined to insecticide-treated crops, for example, the spotted alfalfa aphid and the onion fly. In this respect, the chemical control of alternative weed hosts is potentially harmful.

From the foregoing conclusions it seems likely that unless chemical control methods are greatly intensified, most pests of arable crops in this country are unlikely to develop resistance. For example, many aphids such as the black bean aphid are controlled by chemicals on certain crop hosts, not on their weed hosts during June or July. No selection for resistance occurs during the rest of the year when frequent aerial migrations prevent populations becoming isolated and when important natural controlling factors are operating which do not selectively favour the insecticide-resistant individuals. Wireworms also are unlikely to develop resistance because most breed in permanent grassland which is not treated with insecticides. On the other hand, the carrot fly might well develop resistance, because the species is largely confined to treated crops and is normally controlled by an insecticide soil treatment of high residual toxicity.

Conclusions

In this country, only red spider mites have developed resistance to insecticides. This is partly because pest problems both in agriculture and public health are not as serious here as in many other parts of the world and insecticides are therefore not often used intensively. For this, we must be grateful to our climate and, in agriculture, to our traditional farming methods, which generally avoid the serious pest problems created by monoculture.

Resistance is most likely to develop in insect pests of fruit, market-garden and glasshouse crops, which are intensively treated with insecticides, often under conditions of monoculture, and it will undoubtedly become more common with increasing use of insecticides. Except with the red spider mites, we are still fortunate in being able to aim at preventing the development of resistance, and this may be avoided or at least delayed, by chemical control methods in which different types of chemical are used in turn. However, we need to know more about the biology and ecology of pest species, for only this extra knowledge will provide a rational basis for control in which chemicals are used, in such a way that they interfere as little as possible with methods of cultural and natural control which do not selectively favour the insecticide-resistant individuals.

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Physical Aspects of the Efficiency of Sprays

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SPRAYING with insecticides, fungicides, or herbicides is now an integral part of agricultural and horticultural practice; the active component being sprayed as a solution in oil or water, as an aqueous suspension, or as an emulsion. Depending on their rates of application, the sprays may be distinguished as high- or low-volume; the former are usually produced by hydraulic sprayers and the latter by mist blowers.

However, methods must be related to the crop under consideration; high-volume spraying on fruit trees would need 200–500 gal/acre whilst for potatoes 100 gal/acre would be required. The real distinction lies in the nature of the resultant spray deposit. High-volume spraying is continued beyond the point of run-off leaving a partially or completely wetted target surface, whilst low-volume spraying gives a deposit of discrete droplets without run-off. To emphasize the importance of the final spray deposit Long Ashton has for some years defined the dosage applied as micrograms of active material per square cm of plant surface rather than lb/acre of crop.

Properties of the Spray Deposit

The formation and properties of the spray deposit are also influenced by the manner in which the pesticide has been formulated for successful practical application. Commercial formulations contain surface-active agents whose purpose may include: stabilization of emulsions, deflocculation or dispersion of suspensions, improved wetting and spreading of the spray fluid and increased adhesion of the dried spray deposit to the plant surface. The manner in which some of these aims may be contradictory is discussed in the following paragraphs.

Although the full importance of the many interacting factors is not completely known, the physical properties of sprays are of considerable importance in determining the ultimate biological efficiency of a spray treatment. During the last ten years new developments in spray techniques and methods of formulation have kindled a renewed interest in the problems of spray deposition and retention. The subject may be considered in separate stages: the fate of the spray droplets after leaving the spray nozzle and spray impaction; spray retention, coverage and distribution of the deposit, and finally the tenacity of the dried spray deposit.

Spray Impaction

Whether the spray fluid is atomized by hydraulic pressure only, by centrifugal energy (spinning discs), or by the interaction of a high-velocity air stream with the liquid (twin-fluid atomizers), the same

basic mechanism of disintegration of the initial thin liquid sheets applies: the fluid kinetics of this process has been reviewed recently by Fraser [9]. Only a small proportion of the droplets issuing from the spray nozzle will reach and hit the target surface. Some of the droplets may be too small and have too low a kinetic energy to penetrate the boundary air layers round the target. Depending on wind velocity and the size spectrum, other droplets may drift from the target area. This is especially serious with droplets below 100 μ diameter applied without the supporting air streams given by mist blowers [30].

Very little is known about the effect of spray supplements on the formation of the spray, but wetting agents, because of their ability to lower the liquid-air interfacial tension, will tend to produce a finer spray [25]. Similarly, suspensions will cause the spray fluid to disintegrate earlier than pure liquids and so will alter the droplet size [9]. This effect is particularly important with the dense suspensions used in concentrated spraying.

REBOUND OF DROPLETS AFTER IMPACT

When the droplets reach the target surface the initial impact during which the liquid spreads across the solid is followed by a contraction of the droplet. The extent of these opposing tendencies is determined by the relation between the initial energy of the droplet and the wettability of the surface. Incorporation of a wetting agent in the spray will ensure that the initial spreading predominates over the "rebound" stage [25] although this will be of lesser importance on an easily wetted surface, e.g., leaves of potato, as compared with cabbage leaves, which are difficult to wet.

In extreme cases where the surface energy is very high, the droplets will bounce off the leaf, a phenomenon often observed on young pea leaves and other leaves with a waxy "bloom". The surfaces from which droplets bounce have a high contact angle with water, which is explained by Hartley and Brunskill [13] as being due to the microroughness of the surface. Electron microscope studies [17] have corroborated this hypothesis by revealing the large number of minute projections of extruded wax which form the surface ultrastructure of many leaves.

Spray Retention

To a large extent the efficiency of a spray depends on the amount of pesticide actually retained by the plant surface at the completion of spraying. The level of deposit, termed the initial retention, is controlled not only by the type of spray and its physico-chemical properties, but also by the gross morphology of the plant and by the nature of the plant surface. The size, shape, rigidity and orientation of the leaves will affect the retention; thus plants with erect cylindrical leaves, such as onion, retain less than do the dorsi-ventral leaves of many dicotyledenous weeds [2].

Ability to wet the surface of a leaf differs widely not only from species to species but even between leaves of different ages on the same stem [8]. Ennis *et al.* [6] found that the retention, and hence susceptibility of soya bean to 2,4-D varied with the hairiness of the leaf surface; a hairy leaf retained twice as much spray as a hairless one. With completely wetted leaves Somers [33] has shown that retention increases with increasing ability to wet the leaf surface. Copper fungicide deposits from the same formulation were retained in the order potato > bean > laurel.

CONDITIONS FOR EFFECTIVE DEPOSITION

Low- and high-volume sprays require different conditions for effective deposition. A satisfactory low-volume spray deposit consists of a number of discrete droplets evenly distributed over the plant surface to give good coverage. The area of spread of the droplet is governed by its kinetic energy on impact and its spreading ability. However, during evaporation the perimeter of the droplet recedes, carrying back spray material to give a smaller zone of deposit than that of the original droplet. Adding a surface-active agent to the spray fluid will reduce the contact angle between the surface and droplet and so increase its spread whilst decreasing recession before evaporation [10]. Too great a concentration of wetting agent may cause the droplets to coalesce and run off the surface.

CONTINUOUS FILM OF LIQUID

With high-volume spraying the aim is to drench the target surface completely so that a continuous film of liquid remains after the excess fluid has drained off. To ensure that no discrete droplets remain on the surface the spray should possess wetting in addition to spreading ability. However, this type of run-off deposit will be lower, although more uniform, than that from a spray with an intermediate degree of wetting [25]. Martin [19] has shown that the maximum initial retention occurs at the point of incipient run-off and that this deposit decreases with increasing wetting ability of the spray.

The value of a wetting agent for run-off sprays must therefore be appraised for each specific use. When the surface is virtually unwettable, as with the leaves of cabbage or banana, the droplets will bounce and roll off the surface if a wetting agent is not incorporated, whilst with a wettable leaf such as potato, the retention will be lowered by the addition of a surface-active agent to the spray fluid. Kearns and Martin [18] reported that the addition of a non-ionic wetter to Bordeaux mixture increased the deposit on banana leaves by a factor of three. Blackman *et al.* [3] found that lowering of the surface tension of a spray fluid by the introduction of a wetting agent increased the retention by barley and pea but decreased that of sunflower and white mustard.

TYPE AND CONCENTRATION OF WETTING AGENT

Even when the surface is completely wetted, the type and concentration of wetting agent used can have a profound effect on the level of run-off deposit. The retention of Burgundy mixture by leaf surfaces was found to be greatest when non-ionic surface-active agents were used; above a critical concentration the anionic succinate wetters gave a marked reduction in deposit level [33]. The nature of the wetting agent can also be responsible for crop damage; Furmidge [11] has shown that, at high enough concentrations, some of the ionic surface-active agents are phytotoxic to plum and apple leaves.

OIL/WATER EMULSIONS

The active component is not always applied as an aqueous solution or suspension; it may be dissolved in oil and formulated as an oil/water emulsion stabilized by a surface-active agent. Ideally, maximum deposition of the toxic agent will be obtained by the preferential retention of the oil phase of the emulsion. This occurs as the concentration of the emulsifier is reduced [7], but at the same time there is a decrease in emulsion stability so that the storage properties of the formulation are impaired. One solution to this problem would be to use as an emulsifier a compound which reacts with the leaf surface so that the emulsion breaks on impact to give an increased deposit of oil. Maxwell [24] has proposed the use of a cationic emulsifier to give a positive charge to the oil droplets rendering the emulsion unstable when in contact with negatively charged foliage.

Coverage and Distribution

The biological efficiency of a spray deposit is dependent not only on the amount of deposit but also on the coverage and distribution achieved. These factors are particularly important when the deposit is to be protective in action, as with fungicides and contact insecticides, rather than systemic, e.g., herbicides and systemic insecticides. Distribution must be differentiated from coverage. A deposit may entirely cover the leaves yet be unevenly distributed, or a considerable proportion of the surface may be untouched by a deposit that is evenly distributed [23].

Surface-active agents give increased coverage of the crop by improving the wetting and spreading properties of the spray. With high-volume spraying, the run-off film often drains to the leaf edges leaving an uneven distribution of the toxicant.

MEASURING DEPOSITS

The methods available for measuring coverage and distribution are largely qualitative, although Martin [21] has used a coefficient of variation of deposits, obtained from the analysis of small areas, as a measure of distribution. Impressions of deposits as they occur on leaves may be

made on media such as moist filter paper [4], plaster of Paris [20], cellulose acetate and gelatin [1], and a picture of the distribution given on development with a reagent or on microscopic examination. Thus, copper fungicide deposits are developed with sodium diethyldithiocarbamate and as little as 0·02 μg copper can be detected visually. Some of the most recent methods are the incorporation of a fluorescent tracer with the active component [36]* and the development of an autoradiogram of a deposit of a fungicide which has been initially activated by neutron irradiation [28].

WHICH DEPOSITS ARE MOST EFFECTIVE?

At the present time there is not a great deal of information available as to the most effective deposits required for the control of specific pests and diseases. Complete coverage of the surface will be more important for fungicides than for insecticides [22]. The mobile insect can move across the sprayed surface to pick up a toxic dose whereas an incipient fungal infection is localized. The zone of inhibition of a spray deposit can be greater than its physical coverage, and some deposits are biologically effective when as little as 5 per cent of the crop surface is covered [5]. This may be due to re-distribution of the deposit, aided by a wetting agent, or else to the formation of a toxic film on the leaf surface produced by solution of the active agent in surface moisture, perhaps aided by leaf or spore exudates. Morgan [26] has clearly shown that the zone of fungicidal action of a copper deposit increases markedly as the deposit is fragmented into smaller aggregates.

High-volume spraying is wasteful of materials and labour and recent developments in spray machinery have largely been concerned with low-volume application. However, the complete coverage given by a drenching spray is still regarded as the most suitable for heavy infestations of certain insects such as woolly aphid, pea moth and pea thrips, and for the dinitro weed killers, DNC and dinoseb [14 and 16].

Tenacity of the Spray Deposit

The dried particulate deposit remaining on the crop after the completion of spraying is subjected to many forces which tend to lower its efficiency. The weathering action of sun, wind and rain and the growth of new foliage all reduce the level of deposit. Rain is generally considered to be the chief weathering agent, but wind and the rubbing of foliage can also be important. Copper fungicide deposits were found to be reduced by 50 per cent with wind alone as compared with a loss of 70 per cent by rain alone [35].

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* A brief account of the scope and use of fluorescent tracers in sprays and dusts has already been given in an article by L. N. Staniland, *N.A.A.S. Quart. Rev. No.* 44, pp. 154–7.

SMALLER PARTICLES GENERALLY MORE TENACIOUS

The tenacity of a spray deposit, defined as the ratio of amount of residue at a given time to its initial level, is determined by the physical and chemical properties of both toxicant and sprayed surface. As tenacity is a surface phenomenon, small particles are generally more tenacious than large ones because of their greater surface area per unit weight and their greater deformability [35]. In formulating spray chemicals this effect must be balanced against the increased rate of oxidation, solubility etc. of smaller particles. Experiments with copper fungicides have shown their adhesion to leaves of varying wettability, hairiness or smoothness to be related to the chemical nature of the surface rather than its microstructure [35]. With dense deposits, especially of hydrated suspensions such as Bordeaux mixture, the particle-particle cohesion overshadows the particle-surface adhesion as the determining factor of tenacity [29].

Laboratory investigations have shown tenacity to be the same whether the deposit consists of discrete droplets or any intermediate level up to a continuous film [35]. Opposite results have been reported from field trials in which low-volume spray deposits were found to be more rain-resistant than those from high-volume spraying [12 and 28]. As it is impossible to achieve equal initial deposits from the two methods of spraying under field conditions, the increased tenacity of low-volume sprays may be more a measure of improved penetration and retention, especially on the underside of the leaves, than a true difference in tenacity.

"STICKERS" TO INCREASE RETENTION OF DEPOSIT

The formulation of the active agent has a marked influence on the tenacity of the spray deposit. Wetting agents are particularly deleterious as they allow rain to re-suspend the deposit and then wash it from the crop surface. Supplements, called stickers, can be added to the spray to increase the tenacity of the deposit. The materials used have been chosen on an *ad hoc* basis from such general adhesives as plant flours and gums, casein products, and natural resins. In an examination of nearly fifty representative stickers, Somers [32] found that most of the materials that increased the tenacity of the deposit did so at the cost of reduced biological efficiency. The most effective supplement was polyvinyl acetate latex which improved the suspending properties of the fungicide in addition to increasing tenacity, although its value in field trials is as yet unproven [34]. Recently, linseed oil emulsions have been found to improve the fungicidal control by phenylmercuric chloride sprays, probably by giving oil-coated particles with higher initial retention and tenacity [31].

In practice, there are two factors which limit the value of stickers. The first is the growth of new foliage which needs to be protected by further spraying; banana leaves, for instance, must be sprayed every

two weeks during the period of rapid growth [18]. The other is that the efficiency of the deposit may be dependent upon re-distribution by weathering. Experimental evidence for redistribution is difficult to obtain and at present only isolated results are available [15].

Key to Improved Spraying Efficiency

Because of the large number of interacting factors that govern the efficiency of a spray, each spraying operation should be considered individually. Surface-active agents should not be used indiscriminately but should be selected with regard to the formulation and crop requirements. Different crops will require different formulations to achieve maximum retention on the foliage. As improvements in formulation and application are made it is probable that lower dosages of toxicant will suffice. The key to improved efficiency of spraying lies in more knowledge of the optimum type and minimum levels of deposit which are required for the control of specific pests and diseases.

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Verticillium Wilt of Lucerne

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THE CAUSAL ORGANISMS of this vascular disease of lucerne are *Verticillium albo-atrum* and *V. dahliae*. Although the disease induced by the latter is of no economic importance, that caused by *V. albo-atrum* spreads very rapidly in an affected field and is causing very serious losses in all the lucerne-growing areas of Britain.

Symptoms

Irrespective of the identity of the pathogen, the symptoms of the disease are identical.

External. The external symptoms can be readily recognized in the field from May to September, but in late autumn recognition becomes more difficult because of the similarity of the symptoms and natural die-back in healthy plants.

Diseased plants show a "flagging" of the upper leaves during warmer periods of the day with some recovery as temperatures drop towards evening. As the disease progresses the leafy shoots show more permanent symptoms, the affected leaves become pale yellow and desiccated and are easily detached, so leading to a rapid defoliation (Plate I). New, apparently healthy, shoots quite frequently develop from the crown regions of infected plants, but this recovery is only temporary since these shoots quickly develop wilt symptoms.

The basal parts of severely infected stems usually become covered with conidiophores of *Verticillium* giving a superficial grey appearance, which, as the stem dies, turns black (Plate II) due to the formation of the resting structures of the fungus.

Internal. Cut stems and roots of infected plants show the dark-brown discoloration of the xylem (Plate II) characteristic of *Verticillium* diseases, from the small lateral rootlets through the stems up into the petioles and into the flower pedicels. The fungus can be isolated from all these regions.

During the initial stages of infection the fungus is confined to the vessels and tracheids but as the stems die the hyphae pass out into the parenchymatous vascular ray and invade the cortex (Plate II) and epidermus, forming first, the superficial conidiophores, and later, the black resting structures.

Seasonal Cycle

The earliest symptoms of wilt in an infected field may occur during the early spring when isolated stunted plants may be so severely infected that they lose their ability to regenerate new shoots and so die, to become the focal centre of infection. After each cut, the regrowth on infected plants—except for those isolated, stunted and dead—at first appears quite healthy, but the onset of symptoms is rapid. The incidence of disease becomes more widespread as the season advances and as the ley ages—in many fields the incidence of infection has increased from approximately 1·0 per cent in the first harvest year to over 50 per cent in the third, when the crop is worthless. Lucerne which has been re-sown on previously affected land has shown a quicker onset of the disease.

Spread of Disease

Seed. Outbreaks of this disease have been observed in crops during their first year of growth in soil where no lucerne had been cultivated in living memory. This, together with the fact that the fungus has been isolated from commercial seed samples, points to the seed as being a means of dissemination of the disease. The fungus has never been obtained from seeds, but from plant debris carried *with* the seed—probably pieces of pods and pedicels which have passed through the threshing machine and mixed with the seed, and which cause the initial outbreak of disease in a seedling crop of lucerne.

Once infection has appeared, its subsequent rapid spread is due to spores and diseased stems and leaves being wind- and/or machine-carried.

Spores. It has been stated above that verticillately-branched conidiophores develop at the base of infected stems. When the crop is cut, the knife passing through these regions induces spore dispersal, either by air currents or carried on the mowing machine, to the cut surfaces of neighbouring plants, causing further infection.

Stems/leaves. Pieces of diseased sporing or non-sporing plant tissue are undoubtedly dispersed at harvesting particularly where the cut crop is blown into a trailer. These fragments will initiate fresh centres of infection either in the same field or, if carried on the implements, in a healthy crop.

In many affected fields, particularly where the original source of infection did not come with the seed, wilted plants are at first more frequent near the entrance and headlands than in the central regions, the disease obviously being brought in by machinery. The spread inwards

VERTICILLIUM

WILT OF LUCERNE

(See pp. 75–9)

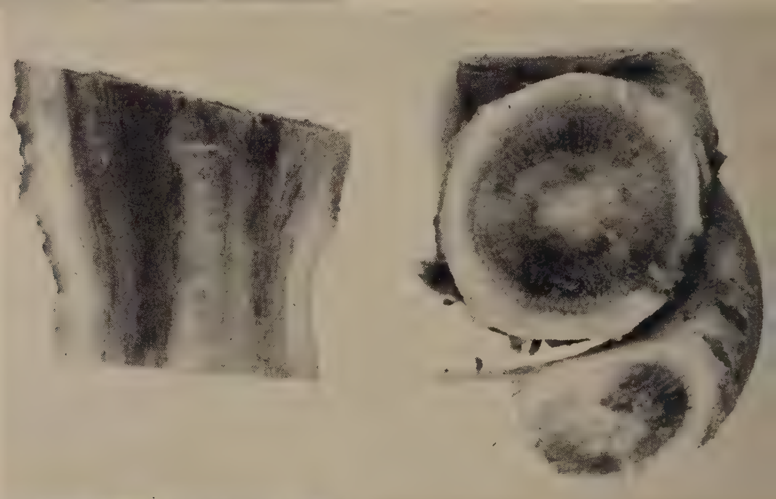
Stages in the development of wilt and defoliation of a diseased lucerne plant.

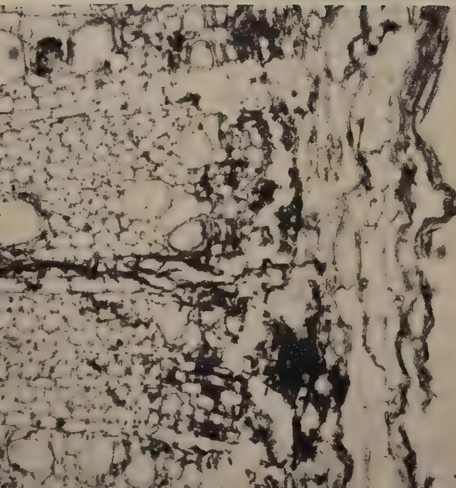
PLATE I

BASAL REGION OF LUCERNE STEMS

Left upper: healthy;

Left lower: infected and superficially blackened due to the formation of resting-mycelium of *Verticillium albo-atrum.*





Above: Transverse and longitudinal sections of stems near the crown region of infected lucerne plants showing discoloration of the xylem.

Left: The resting-mycelium of *Verticillium albo-atrum* in the xylem, vascular rays, cambium and cortex are obvious in this microphotograph of a transverse section of the basal region of a stem of a diseased lucerne plant.

PLATE II

occurs as infected stems and leaves and spores of the fungus are carried into the crop during each harvesting process, thus accounting for the increase in incidence after successive cuts and with the number of harvest years.

Range of Pathogenicity

To investigate the range of pathogenicity of the isolates of *V. albo-atrum* and *V. dahliae* from lucerne, a series of plants of hop ('Fuggle'), potato ('King Edward'), tomato ('Kondine Red'), sainfoin ('Common'), clover ('Dorset Marl, Merker, Double Cut American, Italian Broad Red, American Mammoth and S123') and antirrhinum (*A. grandiflorus*) have been tested, as shown in Table 1.

Table 1
Range of Pathogenicity of Isolates of Verticillium from Lucerne

Plant	*V. albo-atrum*		*V. dahliae*	
	No. of Plants Infected	Symptoms	No. of Plants Infected	Symptoms
Hop	*19/†120	Very mild. Plants recovered in second year	0/10	—
Potato	35/40	Mild	18/20	Mild
Tomato	28/40	Mild	9/20	Mild
Antirrhinum	7/72	Mild	0/6	—
Sainfoin	0/24	—	0/12	—
Clover	0/72	—	0/36	—

* Numerator = number of plants infected.
† Denominator = number of plants tested.
The controls invariably remained healthy.

From Table 1 the conclusion may be drawn that the isolates of *V. albo-atrum* and *V. dahliae* from lucerne are, at the most, only mild pathogens to the tested plants. The importance of these results to the hop growers of Kent is obvious, since this disease of lucerne is becoming widespread in that county and because a strain of *V. albo-atrum* causes a very severe ("progressive") disease of hops. It means that the *V.*

albo-atrum from lucerne will not cause serious trouble if carried into a hop field or if hops are planted after lucerne, although it may induce mild ("fluctuating") outbreaks. These results, together with the fact that *V. albo-atrum* from diseased hop plants in the West Midlands is not pathogenic to lucerne, suggest that the lucerne and hop pathogens are distinct physiological strains.

Since potatoes showed symptoms, however mild, the cultivation of this crop after lucerne should be discouraged, particularly if lucerne is to be sown in the same field in future, because the potato crop will probably increase the reservoir of inoculum. *V. albo-atrum* originally obtained from the potato is not pathogenic to lucerne, so the cultivation of lucerne *after* potatoes should only be recommended if it has not been grown before potatoes.

The cultivation of sainfoin and clover, both resistant to the lucerne pathogens, may be encouraged as fodder crops in those regions most severely affected by lucerne wilt.

Although the incidence of wilt in tomato was fairly high, the symptoms were not severe and an apparently normal crop of fruit was obtained.

The inability of the lucerne isolates to cause severe wilt in antirrhinum is most surprising since all other strains of *V. albo-atrum* and *V. dahliae* tested on this host have been virulently pathogenic, which emphasizes the uniqueness of these lucerne pathogens as physiological strains.

Disease Control

Selection of disease-resistant varieties. In preliminary trials, between 130–140 varieties and/or species of lucerne have been tested against the *V. albo-atrum* isolate with the following provisional results:

Susceptible

(i) All the commercial varieties of lucerne cultivated in Northern Europe and which, according to most authorities, originate from *Medicago sativa*.

(ii) Hybrids of *M. sativa* and *M. falcata*.

(iii) Inbred and polycross progenies originating from these North European varieties.

(iv) Progenies of crossing wild Persian and British types with cultivated lucerne.

(v) Persian and Turkish varieties.

(vi) Progenies originating from South European and Mediterranean lucerne once inbred.

(vii) Most Russian varieties.

Resistant. Under experimental conditions, varieties of lucerne found in North Africa (*M. sativa* var. *gaetula*) and some Russian varieties of *M. sativa* have shown a certain degree of resistance, and these are the subject of further testing and breeding.

Obtaining seed from Verticillium-free areas. There has been, so far, no record of this disease in America and observations are being kept on crops grown in this country both from American once-grown French seed and from seed of native American varieties.

Localizing the disease. Disinfection of all machinery, footwear etc. with a fungicide, e.g., formalin, before leaving an affected field is recommended and, if practicable, healthy crops should be cut first before contaminating the machinery with the infected crops.

Seed dressings and fumigants. Since, as stated earlier, the disease is brought into a new area by contaminated plant debris carried *with* the seed, attempts have been made to control its dissemination by the use of seed dressings to destroy the fungus. Under experimental conditions, Agrosan-GN (1 per cent Mercury) and Fernasan (5 per cent thiram) used in the ratio of 0·5 per cent and 1·0 per cent weight for weight of seed, destroyed the resting mycelium and spores which had been experimentally added in a much greater proportion than normally found in commercial seed samples. Also, although both fungicides had adverse effects upon *Rhizobium mellelotus* when growing in artificial culture, they did not reduce the concentration of the bacterium on inoculated seed below that required to form good nodulation. In fact, seeds which had been inoculated with *Rhizobium* and dressed gave rise to more vigorously growing seedlings than did those undressed. Hence, Agrosan-GN and Fernasan, as well as acting as fungicides against *Verticillium* may also be useful in fostering the early development of a healthy stand of lucerne. Their effectiveness on a commercial scale is the subject of present investigation.

The use of fumigants against the infected pieces of plant tissues carried with the seed is also under investigation, but no positive conclusions are yet available.

For further information concerning this disease, the reader is referred to the articles listed below.

ACKNOWLEDGMENT

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Nitrogen Nutrition of Fruit Crops

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MANURING OF fruit crops is at present based largely on experience and the results of field manurial trials. Recent work has shown, however, that generalization from a few manurial trials may be quite misleading, and that for a rational approach to manuring information is required on at least four aspects:

1. Movement of nitrogen in the soil in relation to chemical form and water supply;
2. Factors affecting uptake and translocation;
3. Current nitrogen status of the crop to be manured;
4. Nitrogen requirement of the crop in relation to growth, yield, and quality of fruit.

These four aspects will be discussed briefly in this article.

Movement of Nitrogen in the Soil

Nitrogen may be applied in one of three forms: organic-N, ammoniacal-N, and nitrate-N. Since the behaviour in the soil of these three forms of nitrogen varies considerably, the effect on the crop will also differ. Complex organic nitrogen cannot be utilized directly by plants although simpler compounds such as urea and some amino-acids are absorbed by plant roots. If organic nitrogen is applied to crops there will be a time-lag, depending on temperature and moisture conditions, before it can be utilized. Further, only a percentage of the total organic nitrogen may be liberated and become available for crop growth during the first season. Nitrification in soil has recently been discussed by Meiklejohn [16] and will not be dealt with here.

Ammoniacal- and nitrate-N move at different rates in colloidal soils and also have different effects on the absorption of other cations. Ammoniacal-N behaves in solution as a cation and is adsorbed by negatively-charged soil colloids, whereas nitrate-N is an anion and is not adsorbed to any appreciable extent by soil colloids. Thus in a loam, or organic soil, the rate of penetration down the soil profile will be slower for NH_4^+ than for NO_3^-. Krantz *et al.* [13] made a study of the movement and behaviour of nitrate and ammonium nitrogen in field soils in relation to rainfall and soil moisture movement. When nitrate-N was placed on the plough sole, a large part was readily moved to the surface during periods of drought, thus becoming unavailable to plants; the nitrate was moved back into the root zone after rain. They suggest that the luxuriant plant growth following rain, after an extended drought period, may be accredited to the effect of the nitrate moved down into the root zone as well as to the moisture.

Ammonium sulphate applied as a top-dressing remained in the top

3 in. of a silt loam soil even after prolonged rains. They estimated that the ammonium adsorption capacity of the three silt loams studied was sufficient to retain ammonium ions, from at least 1,000 lb of ammonium sulphate per acre, in the surface 3 in. of soil.

Losses of nitrate-N from loam soils of good structure are not so great as one would expect from the non-adsorption of nitrate ions on soil colloids. According to Cunningham and Cooke [10], prolonged and persistent rainfall is needed to transport nitrate into the subsoil of heavy soils. They suggest that nitrate ions are retained *inside* structural aggregates, and that rainfall tends to percolate *around* the crumbs and does not remove nitrate rapidly from the interior. Continuous rainfall, which causes deterioration in soil structure, is likely to cause more leaching of nitrate than irregular or light rains, which allow crumb structure to be maintained. Gasser [11] obtained similar results, working with a light soil in a different season; this suggests that the mechanisms of nitrate removal in the two soil types differ in degree rather than in kind.

EFFECTS OF COVER CROPS AND GRASS

So far the movement of nitrogen has been considered only in arable soils, but most top fruit orchards in this country are seeded to temporary or permanent cover crops which have a profound effect on the movement and availability of applied- and soil-nitrogen. Fig. 1 shows the effect of four different cover crops on the leaf-nitrogen status of dessert apples in an experiment at Long Ashton. It is clear from these results that all cover crops reduced leaf-N during the first season. In the second season, trees in natural cover (tumbledown) showed some recovery; trees in a clover cover returned to a normal nitrogen status, whilst timothy and ryegrass had an even greater adverse effect on leaf nitrogen than in the first season. Judging from the very low leaf-N values, and the poor growth of the trees, both these grasses were probably absorbing the greater part of the applied- and soil-nitrogen. In the third season both varieties showed some response to applied fertilizer.

Cunningham and Cooke (*loc. cit.*) studied the effect of grass on the removal of inorganic nitrogen in soil. Within 6 weeks of starting active growth, the grass removed most of the NH_4^+ and NO_3^- provided by fertilizer dressings supplying 112 lb of N per acre. Gasser (*loc. cit.*), working with a lighter soil, found that ryegrass removed nitrate very rapidly from the soil and reduced the level of NO_3^- to <1 p.p.m., both on plots with or without fertilizer-N. On plots dressed with ammonium sulphate, at 100 lb of N per acre, there was a loss of NH_4^+ under ryegrass and no corresponding increase in NO_3^-. Examination of soil samples taken in October from depths up to 3 ft showed no accumulation of mineral nitrogen under ryegrass. The practical implications of these results on the manuring of orchard crops will be discussed later.

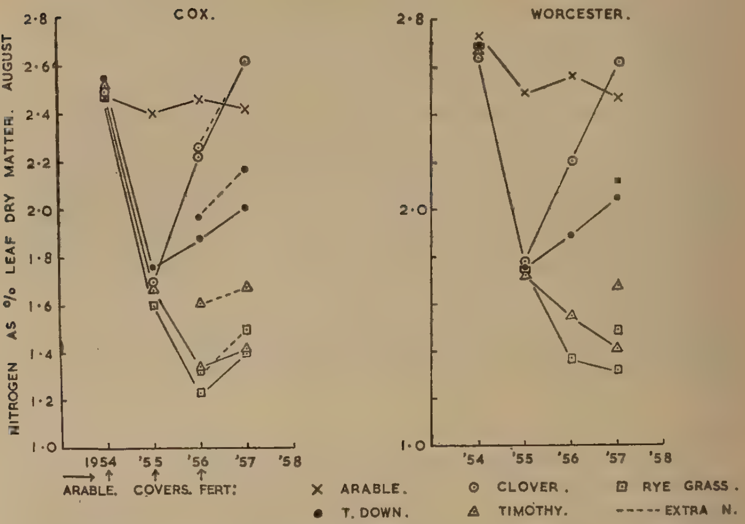

FIG. 1. THE EFFECT OF COVER CROPS ON THE LEAF-NITROGEN STATUS OF DESSERT APPLES AT LONG ASHTON.

All plots receive 2 cwt "Nitro-chalk" per acre in March; from 1956 onwards some of the plots received an additional 2 cwt "Nitro-chalk" per acre. Note the severe effect of timothy and perennial ryegrass on leaf-N, and the relatively small response to fertilizer-nitrogen.

Factors Affecting Uptake and Translocation of Nitrogen

A number of factors affect the absorption and use of nitrogen by fruit crops. Amongst the most important are:

1. Time of application.
2. Presence or absence of a cover crop.
3. Soil temperature and moisture conditions.

Time of application of nitrogen is very important when dealing with young trees in the early stages of grassing-down, for it is then that competition for nitrogen and water is must critical. In the first season after seeding with a cover crop most of the effective feeding roots of the trees are below the plough-sole level, whilst the soil above the plough sole is effectively explored by the cover crop roots. If the nitrogen is applied in the spring, most of it is absorbed by the cover crop before it can penetrate to the tree roots. The results of Cunningham and Cooke and of Gasser (*loc. cit.*) showed the effectiveness of ryegrass in removing both ammoniacal and nitrate nitrogen from the surface areas of the soil, and the effect of grass on the nitrogen status of trees is shown in Fig. 1.

It is logical, therefore, to apply the nitrogen in the previous year, after the cessation of tree extension growth to avoid this temporary immobilization of nitrogen by cover crops, and its subsequent adverse effect on the growth of young trees. The nitrogen will then penetrate to the rooting zone of the tree, where some will be taken up and stored in the roots, and the remainder will be available for uptake in the following spring. Magness, Batjer, and Regeimbal [14] studied the distribution of nitrate-N in the soil, and its subsequent effect on the nitrogen status of established apple trees, when sodium nitrate was applied at different seasons at a rate calculated to give approximately 45 p.p.m. of nitrate-N in a 1-foot depth of soil. They found that most of the nitrate applied in September and October had penetrated to the second- and third-foot depths by the following spring, during which time from 15 to 24 in. of rain had fallen. Nitrate-N applied in early spring remained mostly in the top foot of soil (clean cultivated) throughout the summer, or until absorbed by the tree. The midsummer applications of nitrogen resulted in a relatively high level of nitrogen in roots and shoots during the dormant season. For established trees, they concluded that, if the level of nitrogen metabolism is satisfactorily maintained within the tree, it makes little or no difference at what season of the year the soil supply is replenished.

Nitrogen can be absorbed by trees at comparatively low temperatures provided that the soil conditions are aerobic. Batjer, Magness, and Regeimbal [1] found that appreciable amounts of nitrate- and ammoniacal-N were absorbed and changed to organic form in the roots of dormant apple trees subjected to temperatures as low as 32–33°F, although little if any nitrogen was translocated from the roots during the dormant season. The rate of nitrogen absorption was reduced when the initial nitrogen content of the roots was high, compared with the rate of intake when the nitrogen content of the roots was low. The results show that there is a limit to the amount of nitrogen that would be absorbed and held by the roots during the dormant season, though the intake might be almost sufficient to carry the trees through a season's growth.

From the original observation by Thomas [17], and the more recent work of Bollard [3], it seems that nitrate-N is reduced and partially metabolized in the root prior to translocation to the aerial parts of apple and other members of the Rosaceae family. Bollard found that, after a period of low and fairly constant levels during the winter, the period of flower opening in apple was marked by a rapid rise in the nitrogen concentration of the xylem sap. Within 14 days during this period there was a seven-fold increase in total-N. Organic compounds accounted for most of the nitrogen, and aspartic acid, asparagine and glutamine were quantitatively the most important compounds present.

Examination in 1958 of the xylem sap from the trees in the cover crop experiment at Long Ashton showed that the N-concentrations

prior to flowering were related to the general nitrogen status of the trees in the previous season (Fig. 1). It would appear, therefore, that for the supply of nitrogen in the xylem sap to be adequate during the period from bud-burst to flowering, reserves of organic nitrogenous compounds must be synthesized in the previous season, and that the process of absorption and synthesis can take place during dormancy so long as the soil temperature does not fall below 32°F, and the conditions are aerobic—since absorption is dependent on root respiration.

Methods of Assessing the Nitrogen Status of Crops

With perennial plants it is desirable to know the current nitrogen status of the crop, and its relationship to the optimum concentration, before making fertilizer recommendations. This can be done roughly by visual assessment of leaf colour, or more accurately by chemical leaf analysis. It is essential, however, in foliar diagnosis that leaf samples should be taken according to a recognized procedure, because the composition of leaves varies according to the position on the shoot and the physiological stage at which sampling takes place. This has been clearly demonstrated with black currant and strawberry by Bould [7, 6] and with apple by Mason [15].

Relationship between Nitrogen Status and Crop Yield

Assuming that no other factor is limiting growth, the relationship between leaf-nitrogen and total yield of fruit may be curvilinear. In the deficiency range, application of nitrogen may increase growth and yield without greatly affecting leaf composition. This is followed by a range where further applications of nitrogen increase growth, yield, and leaf-N status. Finally, a point is reached where further additions of nitrogen no longer affect growth and yield but leaf nitrogen continues to increase. The main object of leaf analysis studies is to find for each crop, at particular physiological growth stages, the leaf-N concentration associated with optimum yield of high-grade fruit. This will *not* necessarily correspond with the nitrogen value associated with optimum growth.

In preliminary studies with black currant it was shown by Bould and Catlow [4] that the optimum nitrogen concentration, in leaves from the mid-third region of extension shoots at fruit ripening, was in the region of 2·9 per cent on a dry matter basis. Black currants normally respond to high nitrogen dressings, provided that water and other nutritional factors are not limiting growth. Bould and Catlow [5], comparing organic and inorganic forms of nitrogen, showed that the order of yields over a 5-year period followed closely the leaf nitrogen levels, and that 6 cwt per acre per annum of "Nitro-chalk", applied in the spring, gave the highest yields of fruit. Blood and Heppell [2] have shown that under certain soil conditions black currants will respond to even higher annual dressings of nitrogenous fertilizer.

Recent unpublished work by the writer has shown that in other circumstances low dressings of nitrogenous fertilizer (3 cwt per acre of ammonium sulphate) will maintain an adequate leaf-nitrogen status, and that higher dressings (9 cwt per acre) may depress yields. In one instance this was due to soil acidification, which led to depressed phosphate uptake.

The sufficiency N-value for fully expanded strawberry leaves, at the early fruiting stage, is probably in the region of from 2·5 to 2·7 per cent N in dry matter, the optimum value varying to some extent with the vigour of the variety [Bould, 8]. At this nitrogen concentration, the plants look slightly nitrogen-deficient, but recent experiments have confirmed the low nitrogen requirement of strawberry. This is illustrated by some unpublished data given in Table 1.

Table 1

N×P×K Factorial Manurial Experiment
Effect on Yield of Fruit and Leaf Nitrogen

Strawberry *var.* 'Royal Sovereign' (planted 1955)

(*Mean yield in lb/plot of* 60 *plants*)

Year . .	1956				1957				1958			
Rate* . .	N_1	N_2	N_3	Sig. P=	N_1	N_2	N_3	Sig. P=	N_1	N_2	N_3	Sig. P=
Grade I fruit .	29·7	28·1	27·9	N.S.	45·0	44·6	43·3	N.S.	Grade 1+2			N.S.
Total crop .	47·3	45·6	47·0	N.S.	70·2	71·0	70·8	N.S.	90·4	91·6	92·5	N.S.
% N in leaf D.M. at fruiting .	2·60	2·66	2·72	% 0·1	2·79	2·86	2·90	% 0·1	2·71	2·83	2·93	% 0·1

* N_1 at rate of 1 cwt/acre amm. sulphate
N_2 ,, ,, ,, 2 ,, ,, ,,
N_3 ,, ,, ,, 4 ,, ,, ,,

It is clear from these results that increased rates of nitrogenous fertilizer raised the leaf nitrogen status without significantly affecting yield—in fact there was a tendency for the weight of Grade I fruit to decrease with increased supplies of fertilizer nitrogen—and that a leaf-N concentration at the fruiting stage of about 2·6 per cent in dry matter is adequate (leaf-P and -K were sufficient) for high-grade yields.

The important role that leaf analysis can play in the interpretation of fertilizer experiments is further illustrated in Table 2, which gives some unpublished results dealing with time of application of nitrogenous fertilizers on the yield of strawberry.

Table 2

Effect of Time of Application of Nitrogen on Yield of Fruit and Leaf-N Status

Strawberry *var.* 'Talisman' (planted 1956)

Treatment	Mean yield fruit lb/plot (18 plants originally)								Mean % N in Leaf Dry Matter	
	1957				1958					
	Grade 1	Sig. P=	Market-able	Sig. P=	Grade 1	Sig. P=	Market-able	Sig. P=	Fruiting Stage 8/7/58	After Picking 28/7/58
		per cent		*per cent*				*per cent*		
Spring-N*	8·0	1	19·7	1	19·8	N.S.	35·4	5	3·05	2·53
Summer-N	10·3		24·3		20·5		37·5		2·52	2·18
$\frac{1}{2}$ Spring $\frac{1}{2}$ Summer -N	9·9		23·1		21·6		39·0		2·67	2·20

* N at the rate of 3 cwt per acre of ammonium sulphate (20·6 per cent N).
All plots received 4 cwt superphosphate (18 per cent P_2O_5) and 1 cwt potassium sulphate (48 per cent K_2O) per acre with the spring-N.

From the yield results it is apparent that nitrogen applied in the spring results in lower yields of fruit than a similar amount applied after fruiting, or a split spring-summer application. Without leaf analysis it would not be possible to give a correct interpretation of these results. Reference to the leaf-N values at the fruiting stage, however, shows that the spring application raised the nitrogen level above the optimum, whereas the summer and split dressings were about right. In fact, had the rate in the spring been halved, i.e., 1½ cwt per acre, the results would probably have been as good as those from 3 cwt per acre applied in the summer.

The nitrogen manuring of top fruit, such as apple, is more complicated because one is dealing with a permanent framework, with a spur system complicated by biennial bearing in some varieties, with cover crops and with management.

Several workers have studied the relationship between leaf composition, yield, and quality of apple. Hill [12] found in two varieties of apple a highly significant negative correlation between foliage nitrogen in July and subsequent storage. In the variety 'Northern Spy' a marked decrease in the quality of the fruit occurred when leaf nitrogen exceeded 1·9 to 2·0 per cent in dry matter, and a similar decrease in the variety 'McIntosh' when foliage nitrogen exceeded 2·0 to 2·1 per cent in dry matter. These values are similar to those quoted by Boynton and Compton [9]. Weeks *et al.* [18], working with the variety 'McIntosh', found that an increase in leaf nitrogen of 0·1 per cent, over the range 1·86 to 2·16 per cent dry matter, caused a decrease of 14 per cent in "fancy grade" fruit. It would appear from these and other results that the nitrogen concentration of leaves from the median position of extension shoots in July and August should not greatly exceed 2 per cent in dry matter.

Conclusions

It is evident from the previous discussion that some crops have a higher nitrogen requirement per acre than others. In general, strawberry has a low requirement and black currant a high requirement, with the tree crops somewhere between the two.

It is also clear that it is not possible to prescribe a best rate of application for any particular crop in all circumstances.

In the absence of other limiting factors the yield and quality of fruit crops is associated with the concentration of leaf nitrogen at specific stages of growth.

The logical approach to manuring, therefore, would be to determine these concentrations for each crop, and to adjust the application rates so as to raise, or lower, the level of leaf nitrogen to these values. This approach, based on leaf analysis, is being investigated at Long Ashton.

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Regional Note

Spring Grazing Autumn-sown Cereals

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MANY FARMERS practise spring grazing of autumn-sown cereals, especially in seasons when spring keep is short, or the crop winter proud and there is danger of lodging.

The grazing available from an autumn cereal is almost always an incidental by-product of grain production, and cereal crops other than rye are seldom grown for grazing only. Spring grazing of cereals is practised to a greater extent with sheep than with dairy cattle and as the increasing density of livestock on many farms during the last decade has placed a greater emphasis on the value of the cereal grazing, there has been an increasing need for information on this subject.

Experiments conducted by the N.A.A.S. and others during this period have provided much useful information. Records of grazed and ungrazed crops in Worcestershire and Cheshire in 1949–50 using dairy cows showed that grazing until the end of April reduced the grain yield by some 6 cwt per acre. In these cases nitrogen was not applied to the crop after grazing.

Replicated experiments with wheat carried out by the N.A.A.S. in Kesteven 1948–49 and Northants 1949–50 using sheep, showed similar grain yield reductions by late April grazing.

N.A.A.S. Experiments in Warwickshire and Staffordshire

In 1955–57 a limited number of experiments were conducted by the N.A.A.S. in Warwickshire and Staffordshire, to investigate the effect on the yields of wheat of different dates of grazing, ranging from late March to early May, either with or without a nitrogen top dressing. In

these experiments sheep were used for grazing and the following table summarizes the results:

Table 1

1955–57

(*Mean Grain Yield Cwt/Acre at* 15% *Moisture Content*)

Nitrogen	Nil				2 cwt/acre "Nitro-Chalk"				
Grazing	G0	G1	G2	G3	G0	G1	G2	G3	MEAN
1955	41·9	41·1	37·0	33·3	43·9	42·2	38·4	34·0	39·0
1956	36·1	37·6	37·6	32·3	37·0	40·1	37·2	31·1	36·0
1957	27·5	27·0	26·0	25·4	27·3	25·2	26·9	25·5	26·3
MEAN	35·2	35·2	33·5	30·3	36·1	35·8	34·2	30·2	33·8

G0 = No grazing. G1 = Grazed until mid-April.
G2 = Grazed until late April. G3 = Grazed until early May.

Table 2

Staffordshire 1956

(*Mean Grain Yield Cwt/Acre at* 15% *M.C.*)

Treatment		GRAZING G0	GRAZING G1	GRAZING G2	MEAN (±0·65)
"Nitro-Chalk" Cwt/acre	0	34·1	34·7	37·4	35·4
	2	36·8	36·3	35·9	36·3
MEAN (±1·72)		35·4	35·5	36·7	35·9

S.E. per plot = 1·58 cwt/acre = 4·4%.
S.E. for use in horizontal and diagonal comparisons = 1·89.
G0 = No grazing. G1 = Grazed until mid-April. G2 = Grazed until mid-April and on 1 May.

In 1955 and 1956 there was no reduction in grain yield when the grazing was completed by mid-April, but a considerable reduction when it was continued until the end of the month. There was a particularly noticeable drop in yield of about 8 cwt an acre in 1955 when grazing was not completed until early May even with a nitrogen top dressing.

The 1956 Staffordshire experiment was of particular interest since the G2 plots were grazed from 12–19 April and again grazed bare on 1 May without reducing the grain yield, unlike the Warwickshire plots that were continuously grazed until early May. This raises the whole question of the relative effects on grain yield of short-period versus long continuous grazing, and of short-period grazing at different dates for which experimental evidence is needed. Such information would elucidate whether or not late April–May grazings in wet seasons were worthwhile, when early grazing cannot be carried out without poaching the soil.

In this series of experiments there was a response to nitrogen with most of the treatments, although nitrogen did little or nothing to enable the crop to recover the loss of grain resulting from late April and early May grazing; similar results were obtained in the Kesteven and Northants experiments.

West Midlands Survey

The amount of keep on offer is related to the growth stage, vigour of the crop and indirectly to the date of grazing. In 1957 and 1958 a survey to obtain fuller information on the results of grazing practices was carried out on a small number of farms in widely scattered parts of the West Midlands, and the results are given in Table 3 opposite.

Although only a few cases were recorded and the evidence is, therefore, limited, the data provided some useful information. Grazing was usually completed by mid-April, and it will be noted that except on farm 1, where no nitrogen was applied after grazing, and farms 4 and 6, where the crops were grazed by cows, there were no reductions in grain yields on the grazed area. These figures confirm the results obtained in the 1955–57 experiments quoted above. The figures for farms 4 and 6 show that grazing with cows is more likely to depress grain yields than sheep, particularly on heavy land and in seasons when soil conditions are conducive to severe poaching. The differential between cow and sheep grazing merits further experimental investigation.

As would be expected, the yield of dry matter varied greatly and only on farms 1 and 12 did it approximate that reported by Hayes [1] of 400 sheep-grazing days per acre.

It is difficult to assess the financial value of the grazing for there are many factors involved. On farm 4 it was worth £7 per acre in terms of milk and potentially averaged 420 sheep-grazing days on farms 1 and 12. In addition, and particularly on the heavily stocked farms, the grazing could be of considerable value for resting the grass acreage at a critical time of the year.

The nutritive value of the vegetative growth of cereals in spring has been determined by several workers. Holliday [2] quotes the percentage of crude protein as varying from 27·5 per cent in a dry matter yield of 1·7 cwt per acre on 19 March to 12·6 per cent in a yield of 19·5 cwt per acre on 1 May. Hayes [1] quotes the following crude protein figures for Powys oats—February: 27 per cent, March: 20 per cent and April: 14 per cent, whilst in the West Midlands the crude protein percentages were around 27 per cent on 1 April.

High Nutritive Value

It is clear from these figures that autumn-sown cereals can produce spring keep of a high nutritive value which is suitable for in-milk ewes and cows; its milk-stimulating quality has often been commented on. Care should, however, be taken when grazing cereals in spring as sheep have been known to scour under such conditions. It is safer to introduce

Table 3. Record of Grazing Practices, 1957

Farm No.	Crop	Grazing Dates	Height of Crop *in.*	Dry Matter		Grazed by	Severity of Grazing	Sheep Grazing days/acre		Nitrogen applied after Grazing *cwt/acre*	Grain Field *cwt/acre*		Difference due to Grazing *cwt/acre*	Remarks
				%	*cwt/acre*			Potential	Actual		Grazed	Un-grazed		
1	S147 oats	1/4–6/4 9/4–12/4	8	16·2	14·9	Sheep	Light	477	97	—	19·7	22·1	−2·4	—
2	S172 oats	20/3–10/4	5	20·9	4·2	,,	Fairly Light	135	80	1½ N/C	28·8	24·8	+4·0	½ lb concs. per head per day fed
3	Capelle wheat	26/3–30/3	5	17·1	1·9	,,	Very Severe	60	83	2 N/C	41·7	39·2	+2·5	—
5	,,	15/3–25/3	6	16·4	4·3	,,	Fairly Light	137	97	1½ N/C	36·3	31·2	+5·1	1 lb oats per head per day fed. Slight lodging
7	,,	29/3–16/4	8	13·8	6·7	,,	Fairly Severe	215	196	1 N/C	37·0	34·6	+2·4	—
4 6	,, ,,	27/3–3/4 29/3–9/4	4 7	18·0 15·8	1·9 6·0	Cows ,,	Severe Fairly Severe	40* 22* plus maintenance		2 S/A 2 N/C	31·4 20·5	32·4 28·0	−1·0 −7·5	Supplementary foods fed
							1958							
8	Capelle wheat	21/4–28/4	5	20·3	1·4	Sheep	Very Severe	45	134	2 N/C	37·2	33·5	+3·7	½ lb concs. per head per day + mangolds fed, + run back on grass
9	,,	27/3–23/4	5	19·4	1·6	,,	Very Severe	50	178	Nil	24·2	22·6	+1·6	Run back on grass
10	Dominator wheat	2/4–28/4	4	21·9	2·6	,,	Severe	82	133	2 N/C	40·0	37·6	+2·4	1 lb concs. per head per day
11	Capelle wheat	20/3–9/4	7	23·5	5·2	,,	Moderate	163	75	2 N/C	36·8	20·5	+16·3	½ lb concs. per head per day. Severe lodging on non-grazed area
12	,,	8/3–15/4	10	18·2	11·4	,,	Light	365	95	3 N/C	—	—	—	No yields taken. Severe lodging + bird damage on un-grazed area
13	Pioneer barley	19/3–25/3 5/4–14/4	5	20·2	4·4	,,	Moderate	140	106	1½ N/C	26·0	See remarks	—	Eared early and lodged. Birds removed all grain on ungrazed areas

* = gallons of milk per acre (calculated).

them to the grazing gradually and, if possible, to provide a runback on to a pasture field at the beginning of the grazing period. In this connection Holliday [2] reports other troubles, including bloat, with sheep grazing winter wheat, and possible taints in milk when cows graze cereals; the latter can be avoided by allowing the cows to graze only immediately after milking. In the West Midland survey, under experienced grazing management, no such difficulties occurred.

There is little information available on the comparative yield of forage from the various cereals, although rye is outstanding as a forage producer.

Spring grazing reduces the length and yield of straw. Records of the West Midland crops show that grazing reduced the length of straw by 4–5 in. and the yield by 9 cwt per acre (30 per cent). Lodging was considerably reduced or eliminated by spring grazing and the largest increase in yield was recorded where serious lodging occurred on the ungrazed plot. Lodging increases the risk of bird damage; 50 per cent of the reduced yield on farm 6 was attributed to this. Holliday [2] also reports straw reductions of from 24 per cent for end of March grazing to 53 per cent for May grazing.

On most arable farms this reduction in straw yield represents little or no financial loss when the other advantages obtained by grazing are taken into account. On farms where straw has to be purchased or finds a ready market, the value of the straw must be offset against the benefits of grazing; on farm 6, the 8 cwt per acre of straw lost by grazing was valued at £2 14*s*., the cost of bought-in straw on that farm.

Grazing delays the maturity of the crop, which may be some disadvantage especially in a late district; in the West Midlands the grazed crops were on average 4 days later in ripening than the ungrazed crops.

It seems that the timely grazing by sheep of autumn-sown cereals, if followed by a top dressing, can therefore be practised without any detrimental effect on grain yields, can provide a substantial amount of spring keep with a high nutritive value, and reduce the risk of a crop lodging.

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